International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 10 | Oct 2018 www.irjet.net p-ISSN: 2395-0072

Review paper on study of various Interleavers and their significance

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Abstract:- In digital communication, reliable communication can be performed by reducing the bandwidth in order to fulfill the Shannon's channel capacity rule but if the bandwidth is reduced than it limits the data throughput. By introducing concept of interleaver in encoders and decoders, this problem can be solved and then it is not required to reduce bandwidth. The task is to choose an optimum interleaver technique with change in word length of information bits for best performance of turbo codes. The different types of Interleavers has been studied in this paper to understand pros and cons of different interleaver. The placement of interleaver in turbo encoder and decoder is also discussed. The difference between convolution and block codes is studied to find the advantages of convolution code against block codes. Quality parameters like BER (bit error rate) and BER curve are also studied to understand how to compare the quality of communication on application of different Interleavers.

Keywords: Turbo Convolutional Codes (TCC), BS (Base Station), MS (Mobile Stations), MAP (Maximum a posteriori probability), QPP (Quadrature Permutation Polynomials), RSC (Recursive Systematic Convolution), BER (Bit error rate), Interleaver, Random interleaver, SNR (Signal to noise ratio).

1. INTRODUCTION

In 1948, Shannon predicted that reliable communications are achievable with the use of channel coding specially by adding redundant information to the transmitted messages. However, Shannon did not propose explicit channel coding schemes for practical implementations. Furthermore, although the amount of redundancy added increases as the associated information delay increases, he did not specify the maximum delay that may have to be tolerated, to be able to communicate near the Shannon's limit. In recent years, researchers have been trying to reduce the amount of latency inflicted by using turbo codec's interleaver that has to be tolerated for the sake of attaining a given target performance.

Since the introduction of TCC in 1993, they have received considerable attention as its performance is near the Shannon capacity limit. TCC consists of an interleaver which separates two-parallel concatenated convolutional codes [1].

There are two classical kinds of interleaver, commonly referred to as block and convolutional. In a block interleaver, the input data is written along the rows of a memory configured as a matrix, and then read out along the columns. A variation of a block interleaver is a pseudorandom block interleaver, in which data is written in memory in sequential order and read in a pseudorandom order. In a convolutional interleaver, the data is multiplexed into and out of a fixed number of shift registers [4].

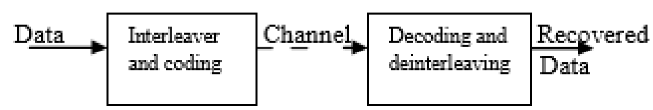

Figure 1. Interleaving

Interleaving is a process of rearranging the ordering of a data sequence in a one to one deterministic format implemented at transmitter side and the inverse of this process is called deinterleaving which restores the received sequence to its original order which occurs at receiver side as shown in Figure 1. Interleaving is a practical technique to improve the error correcting capability of coding.

2. INTERLEAVER

2.1. RANDOM INTERLEAVER

For the implementation of random interleaver, the BS must accommodate a huge amount of memory for storing the random patterns of interleaver, and this results in serious concern of storage when it is required to entertain a large quantity of users. Apart from it, during the initial link of setting-up phase, there should be messages assign between the BS and MS to inform each other about their respective interleaver. Random interleaver scrambles the data of different users with different pattern. Because of the scrambling of data, considerable amount of bandwidth will be consumed for transmission of all these interleaver as well as computational complexity will be increase at receiver ends. Spreading is the important characteristic of random interleaver.

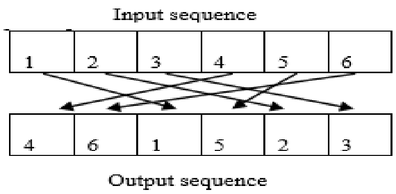

Figure 2. Random interleaver of data

The collision among interleaver is interpreted in the form of the uncorrelation among the interleaver. If the interleaver is not randomly generated, the system performance degrades considerably and resulting in higher values of Bit Error Ratio (BER). On the other hand, if the interleaving patterns are generated more and more random, then better values of BER are obtained for the same parameters [2]. Figure 2 shows randomly selected output sequences out of input sequences in case of random interleaver.

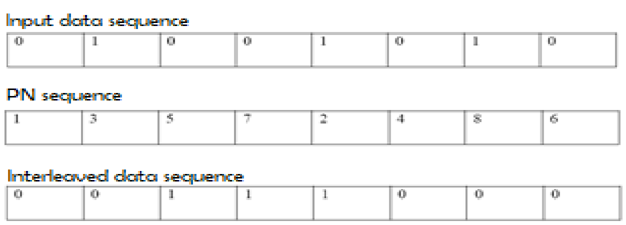

Figure 3. Operation of the Random interleaver

Figure 3 shows the operation of the random interleaver with N=8 [12]. The random interleaver is Pseudo random interleaver in the true sense because a pseudo random number generator or a look up table is used to map the input sequence.

2.2. QPP INTERLEAVER

The benefits of polynomial Interleavers include special performance, complete algebraic structure, and efficient implementation (high speed and low memory requirements) [2].

Parallel decoding can be enabled by using Interleaving/de-interleaving and thus memory access contentions occurs when MAP decoder simultaneously tries to read/write from/to memory. The QPP interleaver is based on algebraic constructions via permutation polynomials over integer rings. It is known that permutation polynomials generate contention-free Interleavers [10]. The QPP Interleaver can be represented by a mathematical formula given an information block length N the x-th interleaving output position is specified by simple quadratic equation (1):

$$f(x) = (f_2 x^2 + f_1 x) \bmod N \qquad (1)$$

Where parameters f1 and f2 are integers and depend on the block size N(0≤x, f1, f2<N) . For each block size, a different set of parameters f1 and f2 are defined. In LTE, all the block sizes are even numbers and are divisible by 4 and 8. The block size N is always divisible by16, 32 and 64 when is 512, 1024, and 2048, respectively. According to definition, parameter f1 must be an odd number whereas f2 must be an even number [11].

2.3. HELICAL INTERLEAVER

A helical interleaver writes data into row–wise but reads data diagonal–wise. An example of helical interleaver is shown below [5]:

X1	X2	X3
X4	X5	X6
X7	X8	X9
X10	X11	X12
X13	X14	X15

Figure 4. Writing data row–wise in memory.

X13	X11	X9	X4	X2	X15	X10	…

Figure 5. Reading data diagonal–wise from memory.

The Helical Interleaver block permutes the symbols in the input signal by placing them in an array in a helical fashion and then sending rows of the array to the output port.

2.4. ODD-EVEN INTERLEAVER

An odd-even interleaver is a block interleaver in which the number of rows and columns must be odd numbers [5]. First, the bits are left un-interleaved and encoded, but only the odd-positioned coded bits are stored. Then, the bits are scrambled and encoded, but now only the even-positioned coded bits are stored. Odd-even encoders can be used, when the second encoder produces one output bit per one input bit.

Odd-even interleaver output														
Encoder output without interleaving														
x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
y_1	-	y_3	-	y_5	-	y_7	-	y_9	-	y_{11}	-	y_{13}	-	y_{15}
Encoder output with row-column interleaving														
x_1	x_6	x_{11}	x_2	x_7	x_{12}	x_3	x_8	x_{13}	x_4	x_9	x_{14}	x_5	x_{10}	x_{15}
-	z_6	-	z_2	-	z_{12}	-	z_8	-	z_4	-	z_{14}	-	z_{10}	-
Odd-even interleaver output														
y_1	z_6	y_3	z_2	y_5	z_{12}	y_7	z_8	y_9	z_4	y_{11}	z_{14}	y_{13}	z_{10}	y_{15}

Figure 6. Operation of odd even interleaver

2.5. MATRIX INTRELEAVER

In the matrix interleaving, bits are fed in a matrix row by row and read out column by column. At the transmitter, the interleaver is used to feed the OFDM symbols with different permutations of the information sequence so that the generated parity sequences can be assumed independent. At the receiver, the de-interleaver is used to randomize the symbols after every decoding step, thus making the iterative decoding more efficient. The column size n is called the depth and the row size m is the span and an interleaver is called as (n, m) matrix interleaver. At the de-interleaver, information is written column-wise and read out row-wise [4].

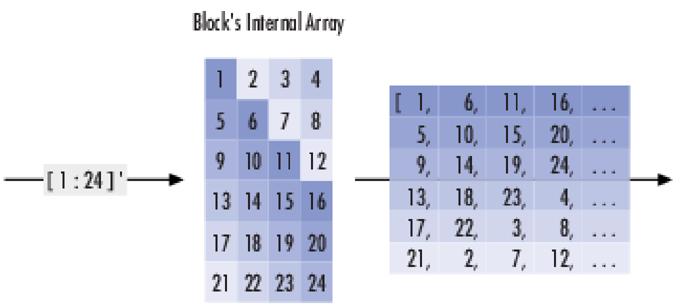

Figure 7. Matrix interleaver

If the Number of rows and Number of columns parameters are 6 and 4, respectively, then the interleaver uses a 6-by-4 matrix for its internal computations. If the Array step size parameter is 1, then the diagonals are as shown in the figure below. Positions with the same colour form part of the same diagonal, and diagonals with darker colours precede those with lighter colours in the output signal as shown in Figure 7.

Given an input signal of [1:24]', the block produces an output of

[1; 6; 11; 16; 5; 10; 15; 20; 9; 14; 19; 24; 13; 18; 23;...

4; 17; 22; 3; 8; 21; 2; 7; 12]

3. TURBO ENCODER

A turbo encoder is the parallel concatenation of RSC codes separated by an interleaver as shown in Figure 7. As per process, the data flow dk first goes into the very first elementary RSC encoder and then it passes through interleaver. At last, it feeds a second elementary RSC encoder. The input stream is also systematically transmitted as Xk, and the redundancies produced by encoders 1 and 2 are transmitted as Y1k and Y2k. The main reason of using RSC encoders for turbo codes in place of the traditional non-recursive non-systematic convolutional codes, is to use their recursive nature and not the fact that they are systematic [9].

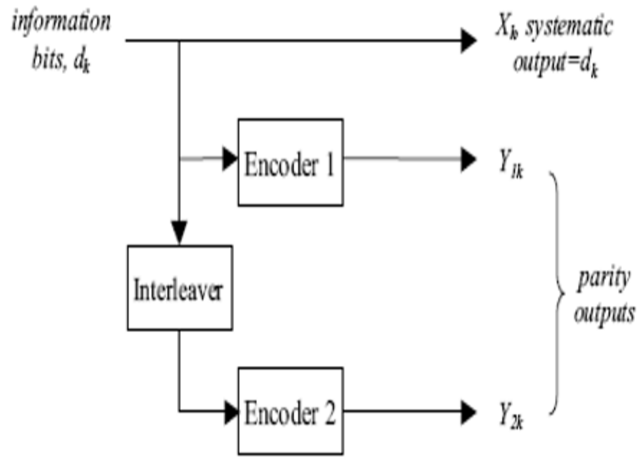

Figure 8. Turbo encoder

A General Turbo encoder is shown in Figure 8. It employs two identical RSC encoders connected in parallel with an interleaver preceding the second RSC encoder. The two RSC encoders are called as the constituent encoders of the Turbo encoder. The information bits are encoded by both RSC encoders. The data frame, length of size N, inserts directly into the first encoder and after interleaving of length N, it feeds the second encoder. Therefore, N systematic bits can generate 2N parity bits and its gives a code rate of 1/3 [5].

3.1 CONVOLUTION CODES

In a block code, the block of n code digits generated by the encoder in any time unit depends only on the block of k input data digits within that time unit but in a convolutional code, the block of n codes digits generated by the encoder in a time unit depends not only on the block of k message digits within that time but also on the block data digits with a previous span of (N-1) time units (N>1). In this way convolution codes are different from block codes. For convolutional codes, k and n are usually small. Convolutional codes can be devised for correcting random errors, burst errors, or both. Convolution Encoder can be easily implemented by using shift registers. It is generated by combining the outputs of a K number of shift registers through the employment of v number of EXCLUSIVE-OR logic summers. For K=4 and v = 3, convolution encoder looks like as shown in Figure 9. Here M1 through M4 are 1-bit storage (memory) devices such as flipflops [4].

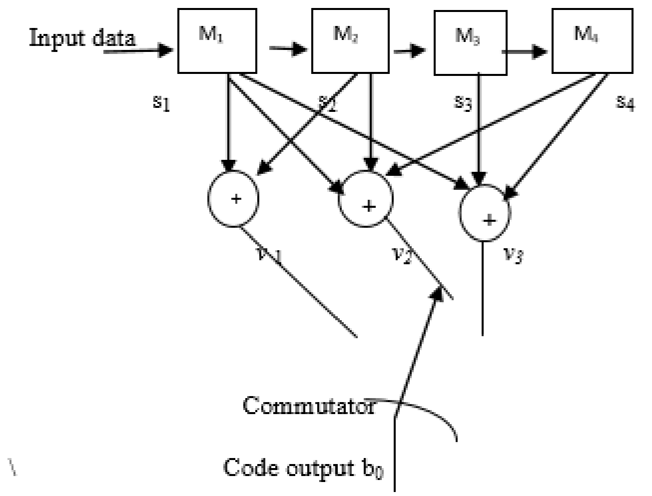

Figure 9. Block diagram of convolutional encoder

4. TURBO DECODER

In a turbo encoder with T constituent encoders, the encoder output contains a single systematic output and T parity outputs from the RSC encoders (assuming no puncturing), T – 1 of which operate on an interleaved version of original data block. Thus, the output of the turbo encoder can be viewed as the output of T independent RSC encoders, except the systematic information only need be transmitted for one of the encoders. The decoder can reconstruct the systematic bits for the other encoders because it knows the interleaving patterns that were used. Thus, the decoder can be decomposed into T convolutional decoders with each one operating on the output of a single constituent encoder. In order to get the best possible estimate of the original message, these separate decoders must be able to share the results of their calculations. To accomplish this, turbo decoders use iterative feedback decoding. Figure 9 shows a schematic of a turbo decoder for the classical turbo code with T=2 [5].

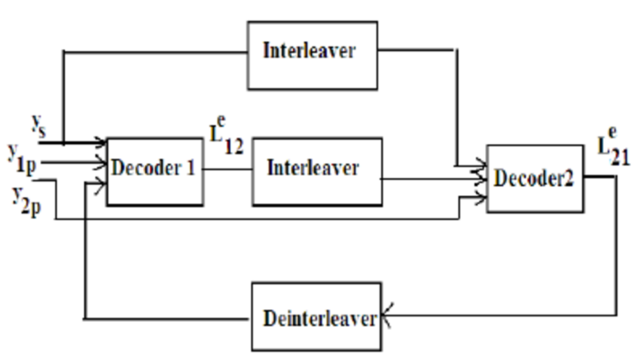

Figure 10. Block diagram of turbo decoder

Since turbo codes have two constituents-code components, an iterative algorithm is appropriate for their decoding. Any decoding method that yields the likelihood of the bits as its output can be used in the iterative decoding scheme as shown in figure 10.

5. EXPERIMENTAL PARAMETERS

5.1. BIT ERROR RATE (BER)

Bit error rate, (BER) is a key quality parameter used to find the quality of system that transmit digital data from one location to another. It is a figure of merit of a receiver. It is an important parameter in radio data links, fiber optic data systems, Ethernet, or any system that transmits data over a network of some form where noise, interference, and phase jitter may cause quality degradation of the digital signal [8].

In the region of high signal-to noise ratio, the performance of any binary code is dominated by its minimum distance dmin (the minimum Hamming distance between code words) and its multiplicity values, Amin (number of code words with weight dmin) and Wmin (sum of the Hamming weights of Amin information frames generating the code words with weight dmin).At very high signal-to-noise ratios (SNR), that is very low error rates, the code performance practically coincides with the union bound, truncated to the contribution of the minimum distance. The BER code performance can then be approximated by equation (2)

$$BER \approx \left(\frac{1}{2}\right)\frac{w_{min}}{K} \; erfc\left(\sqrt{d_{min} \quad \frac{k}{n}\frac{E_b}{N_0}}\right) \quad (2)$$

Where k/n is the code rate and K is the information frame length [6].

5.2. BER CURVE

When a curve is plotted between BER and SNR of Turbo code, the resulting curve has waterfall shape that abruptly flattens. This part is called error floor. The error floor condition occurs due to small minimum distance in turbo code as the performance curve flattens out as shown in Figure 11. There is a large effect on free distance in turbo codes due to interleaving. Appropriate interleaver are used for lowering error floor in turbo codes.

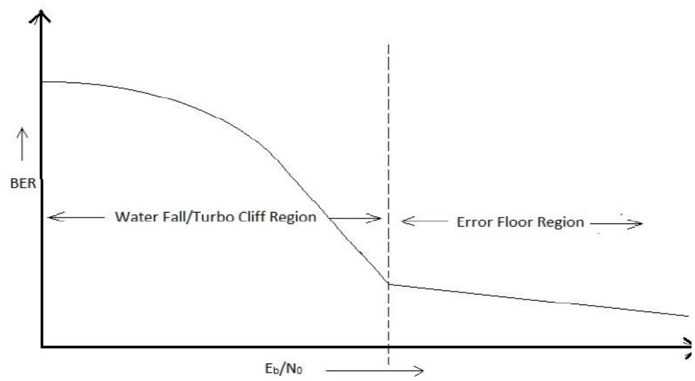

Figure 11. A BER curve showing the waterfall region and the error floor

The interference is due to the external factors and cannot be removed by the system design. However, it is possible to set the bandwidth of the system. By reducing the bandwidth, the interference can be reduced but reducing bandwidth also limits the data throughput [8].

6. CONCLUSION

Turbo encoders make use of interleaver at receiver side and de-interleaver is used at receiver side in turbo decoders. Interleaver is very important for improving the performance of the turbo codes. Quality of an interleaver can be determined by drawing BER curve corresponds to it. Water fall region helps in determining which interleaver is better in which set of conditions.

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